Challenges in Geographic Routing: Sparse Networks, Obstacles, and Traffic Provisioning

Brad Karp

icsi

Berkeley, CA

bkarp@icsi.berkeley.edu

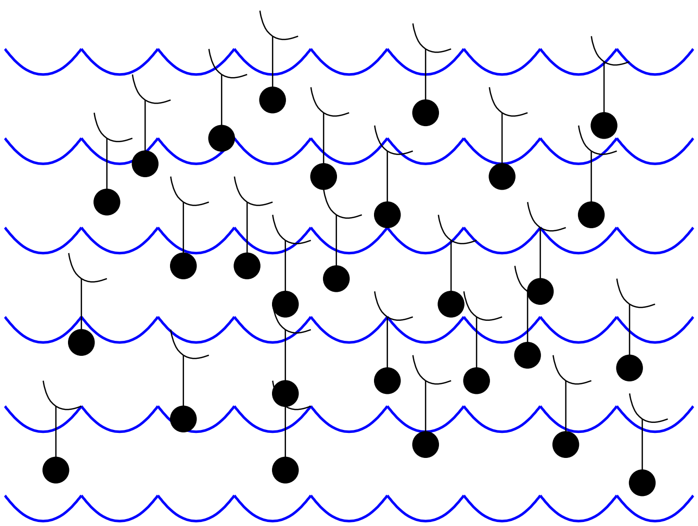
DIMACS Pervasive Networking Workshop

21 May, 2001

Motivating Examples

Vast wireless network of mobile temperature sensors, floating on the ocean's surface: *Sensor Networks*

Metropolitan-area network comprised of customer-owned and -operated radios: *Rooftop Networks*



Scalability through Geography

How should we build networks with a mix of these characteristics?

- Mobility
- Scale (number of nodes)
- Lack of static hierarchical structure

Use geography in system design to achieve scalability. Examples:

- Greedy Perimeter Stateless Routing (GPSR): scalable geographic routing for mobile networks [Karp and Kung, 2000]
- GRID Location Service (GLS): a scalable location database for mobile networks [Li *et al.*, 2000]
- Geography-Informed Energy Conservation [Xu *et al.*, 2001]

Outline

Motivation

GPSR Overview

GPSR's Performance on Sparse Networks: Simulation Results

Planar Graphs and Radio Obstacles: Challenge and Approaches

Geographic Traffic Provisioning and Engineering

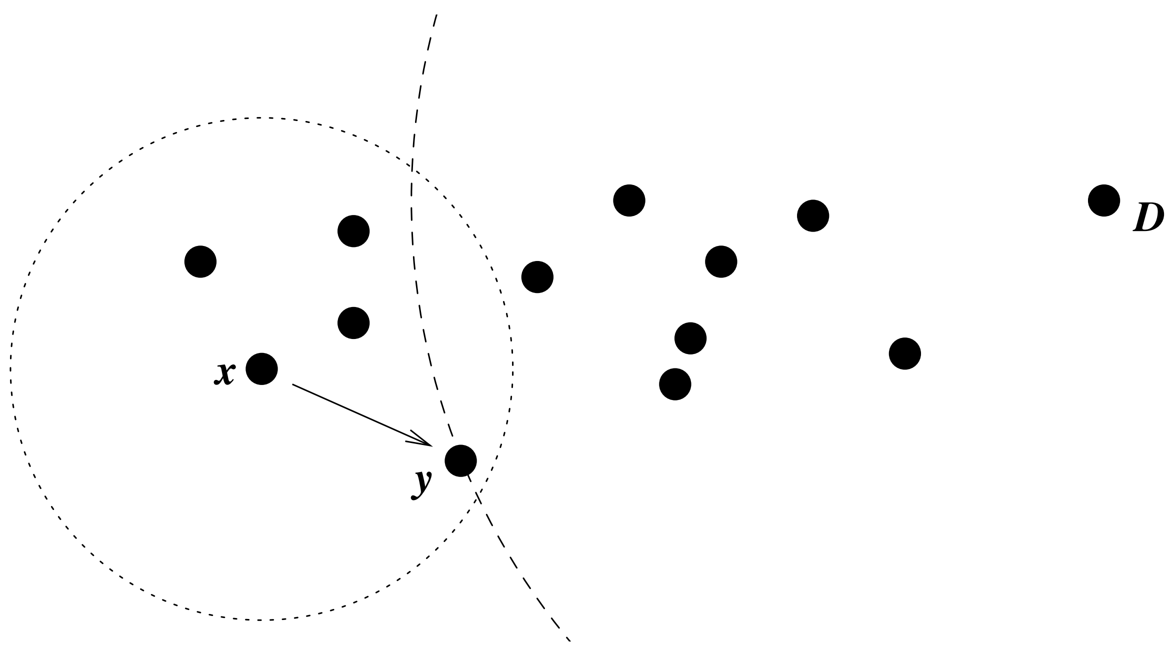
Conclusions

GPSR: Greedy Forwarding

Nodes learn immediate neighbors' positions through beacons/piggybacking on data packets: only state required!

Locally optimal, greedy forwarding choice at a node:

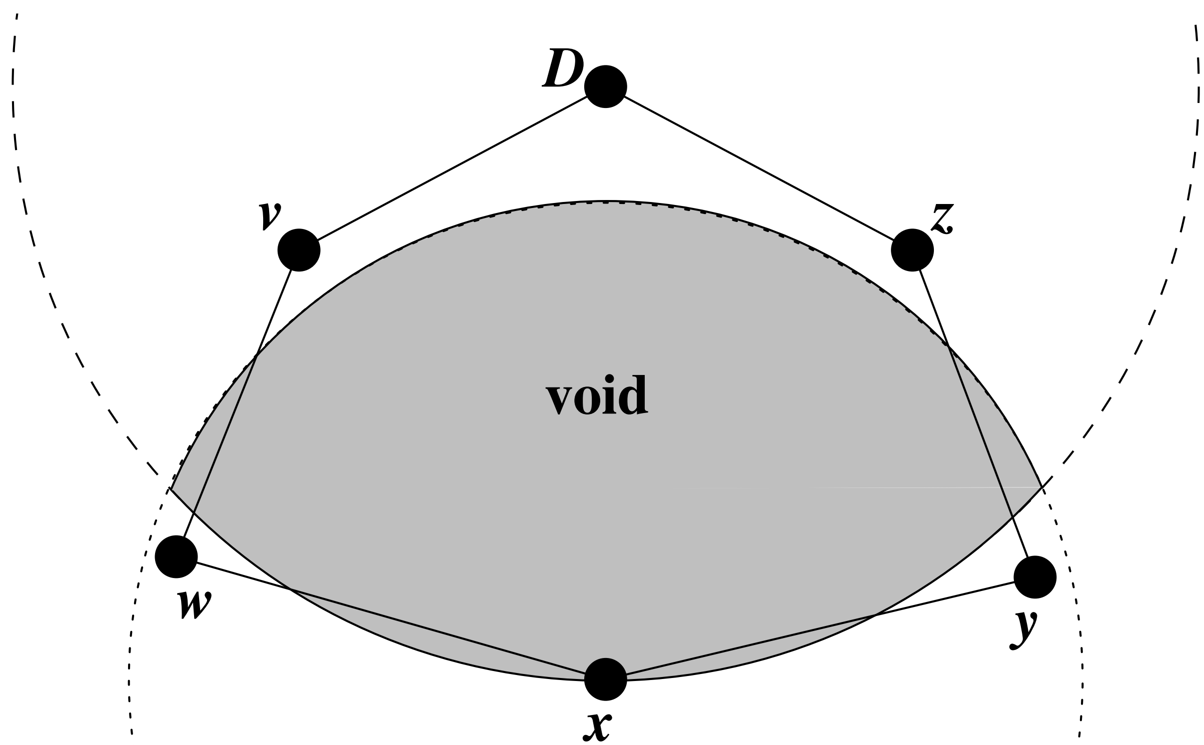
> Forward to the neighbor geographically closest to the destination



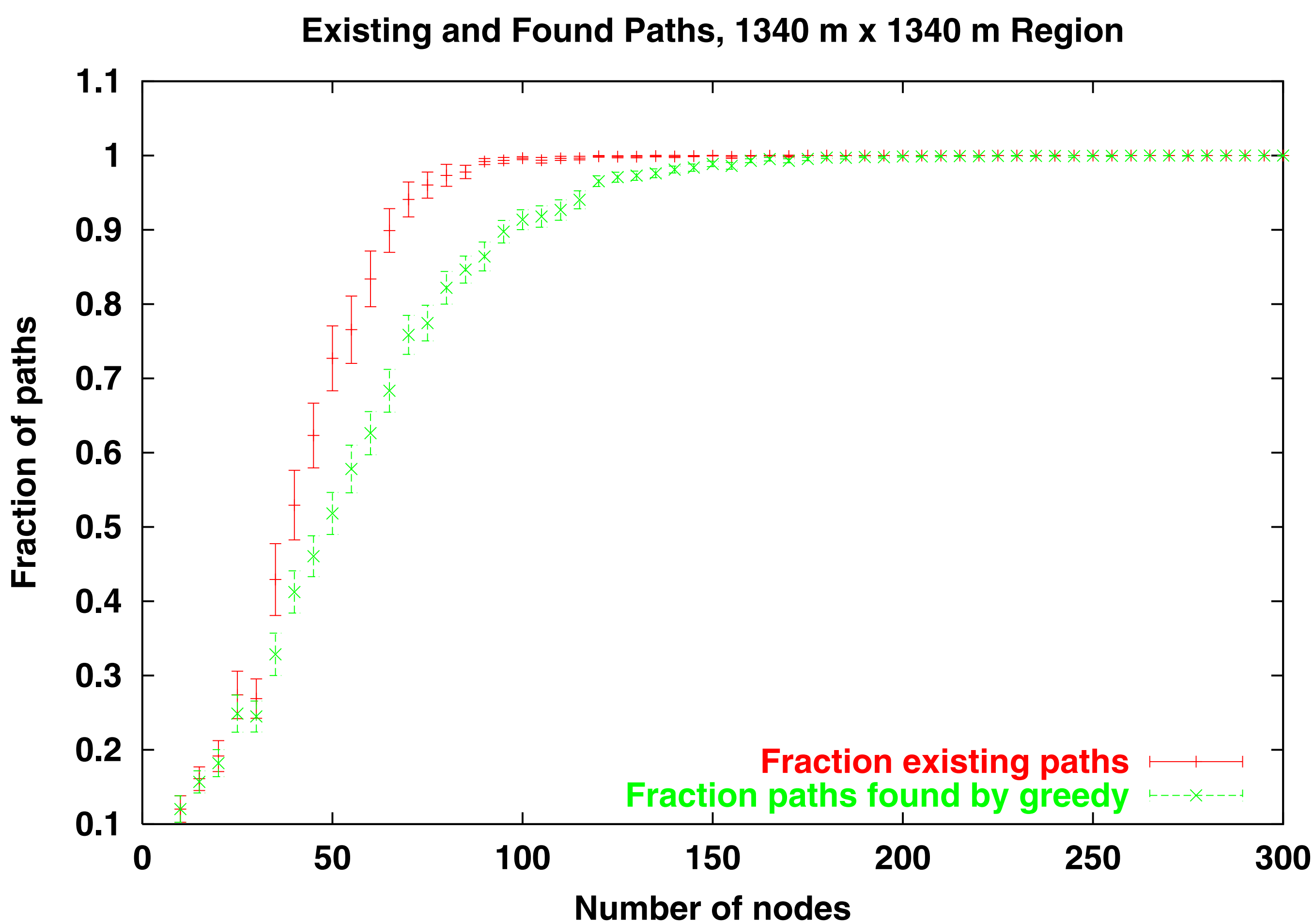
Greedy Forwarding Failure: Voids

When the *intersection* of a node's circular radio range and the circle about the destination on which the node sits is empty of nodes, greedy forwarding is impossible

Such a region is a void:

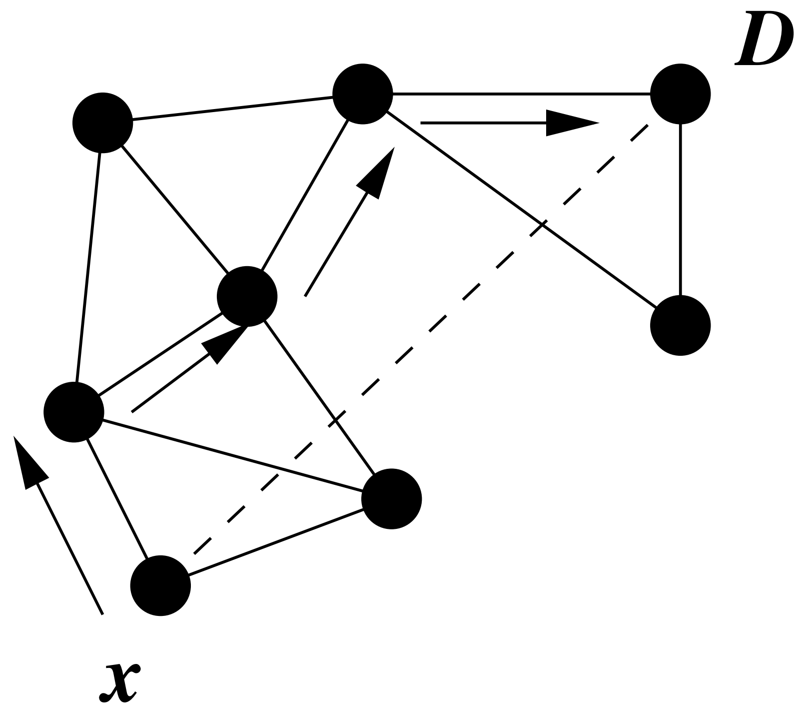


Node Density and Voids



The probability that a void region occurs along a route increases as nodes become more sparse

GPSR: Perimeter Mode for Void Traversal



Traverse face closer to D along $\overline{xD}$ by right-hand rule, until reaching the edge that crosses $\overline{xD}$

Repeat with the next closer face along $\overline{xD}$, *&c.*

Forward greedily where possible, in perimeter mode where not

Challenge: Sparse Networks

Greedy forwarding approximates shortest paths closely on dense networks

Perimeter-mode forwarding detours around planar faces; not shortest-path

Greedy forwarding clearly robust against packet looping under mobility

Perimeter-mode forwarding less robust against packet looping on mobile networks; faces change dynamically

Perimeter mode really a recovery technique for greedy forwarding failure; greedy forwarding has more desirable properties

How does GPSR perform on sparser networks, where perimeter mode is used most often?

Simulation Environment

ns-2 with wireless extensions [Broch *et al.*, 1998]: full 802.11 MAC, physical propagation; allows comparison of results

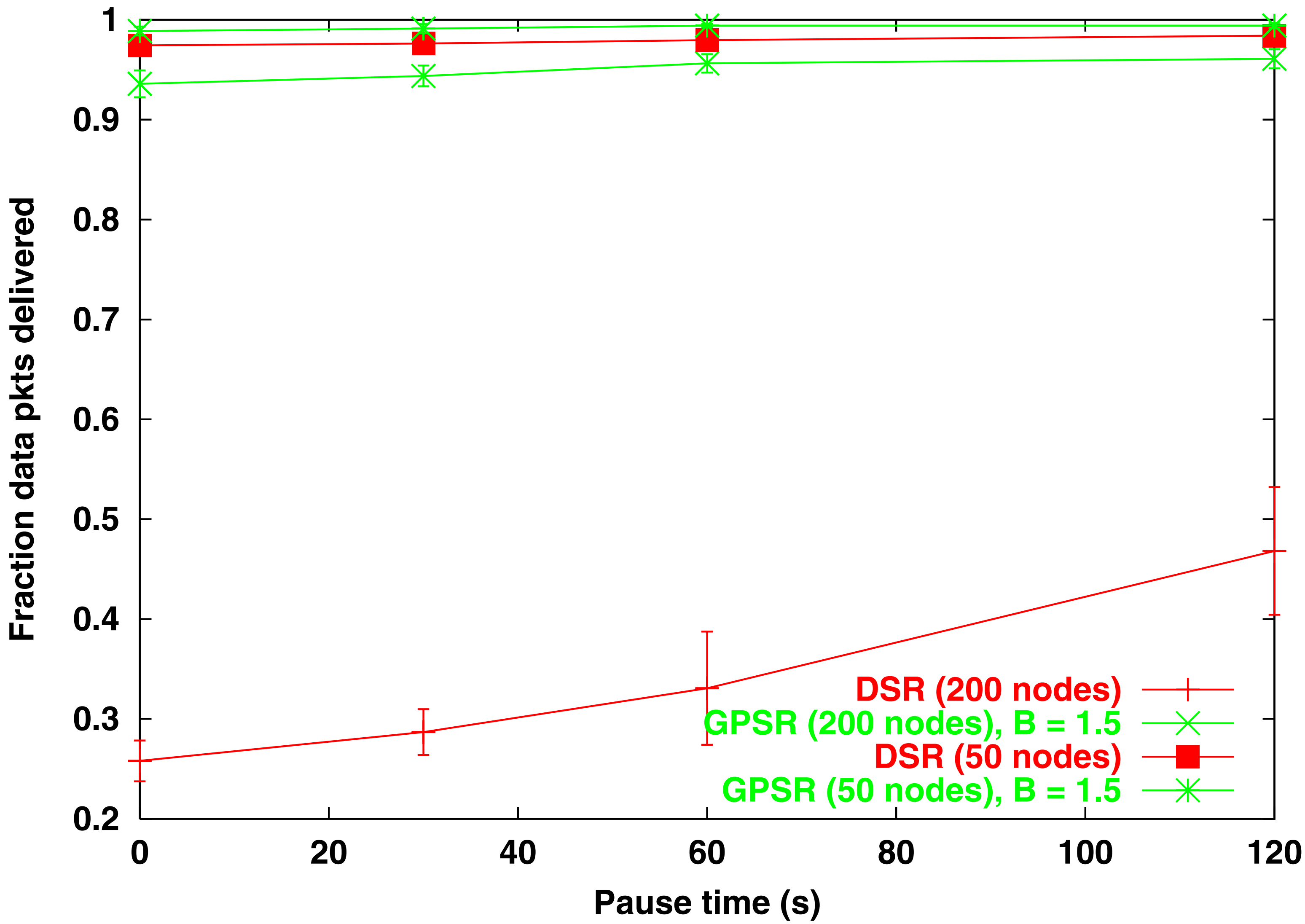
Topologies and Workloads:

Nodes	Region	Density	CBR Flows
50	1500 m $\times$ 300 m	1 node / 9000 m^2	30
200	3000 m $\times$ 600 m	1 node / 9000 m^2	30
50	1340 m $\times$ 1340 m	1 node / 35912 m^2	30

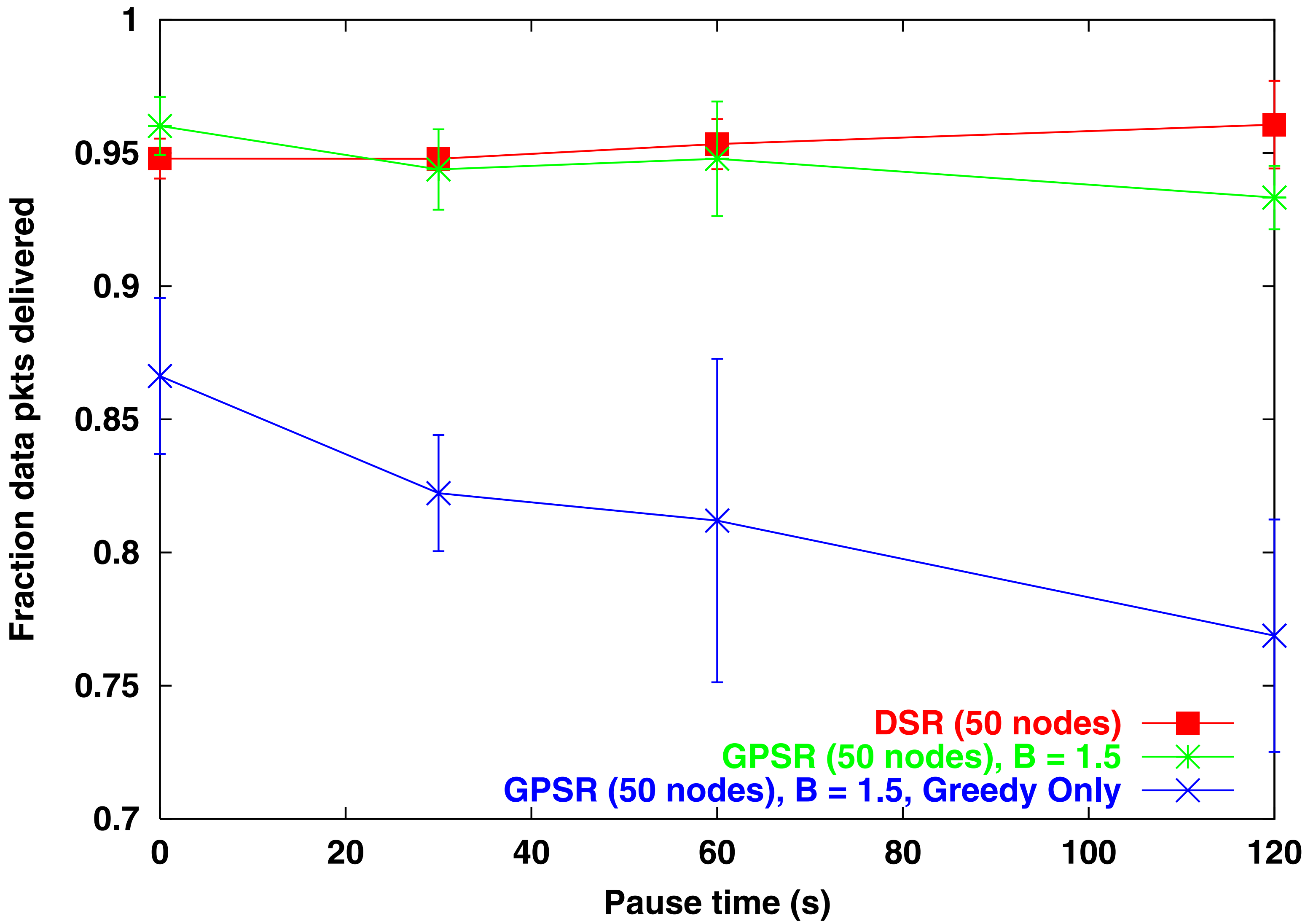
Simulation Parameters:

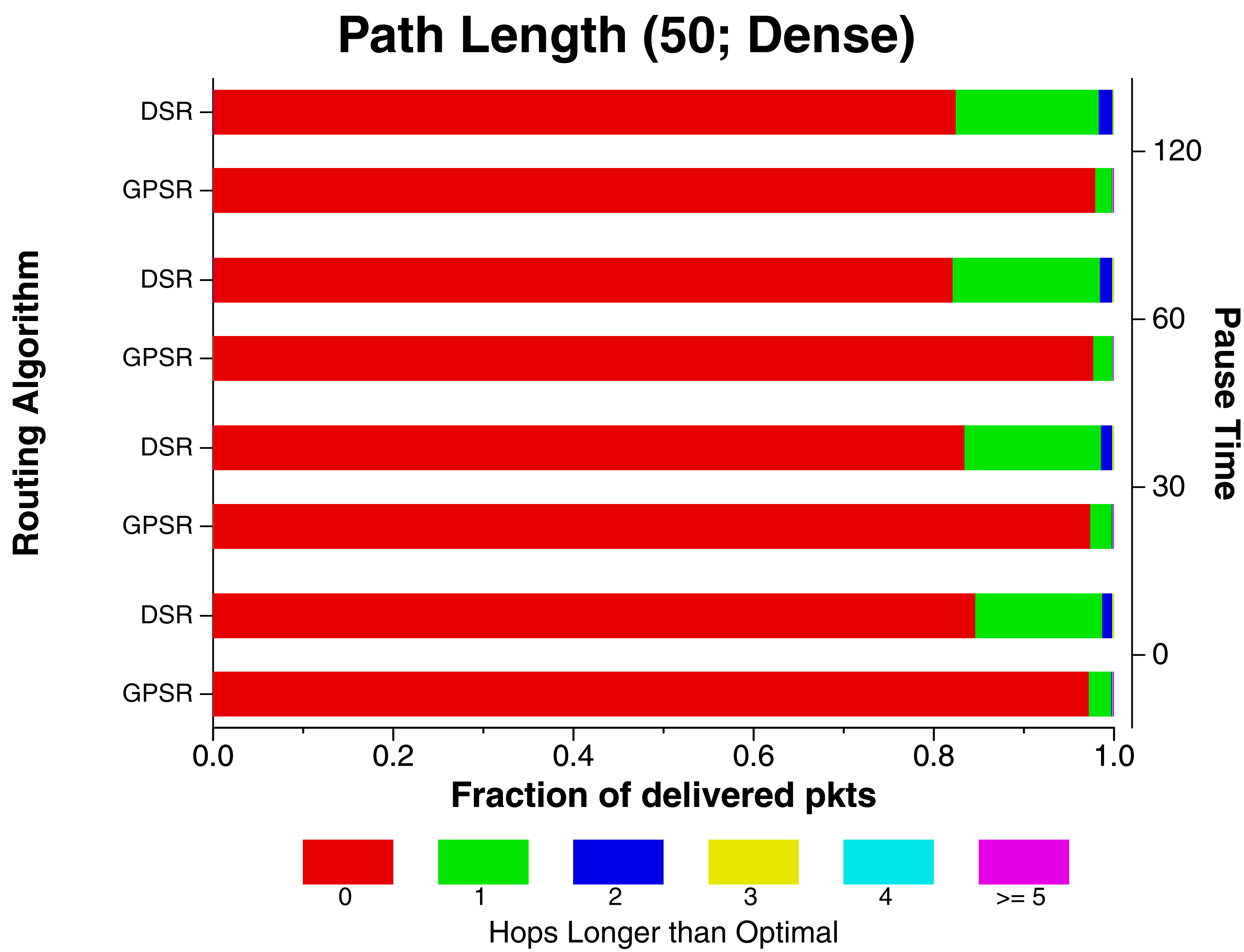
Pause Time: 0, 30, 60, 120 s	Motion Rate: [1, 20] m/s
GPSR Beacon Interval: 1.5 s	Data Packet Size: 64 bytes
CBR Flow Rate: 2 Kbps	Simulation Length: 900 s

Packet Delivery Success Rate (50, 200; Dense)



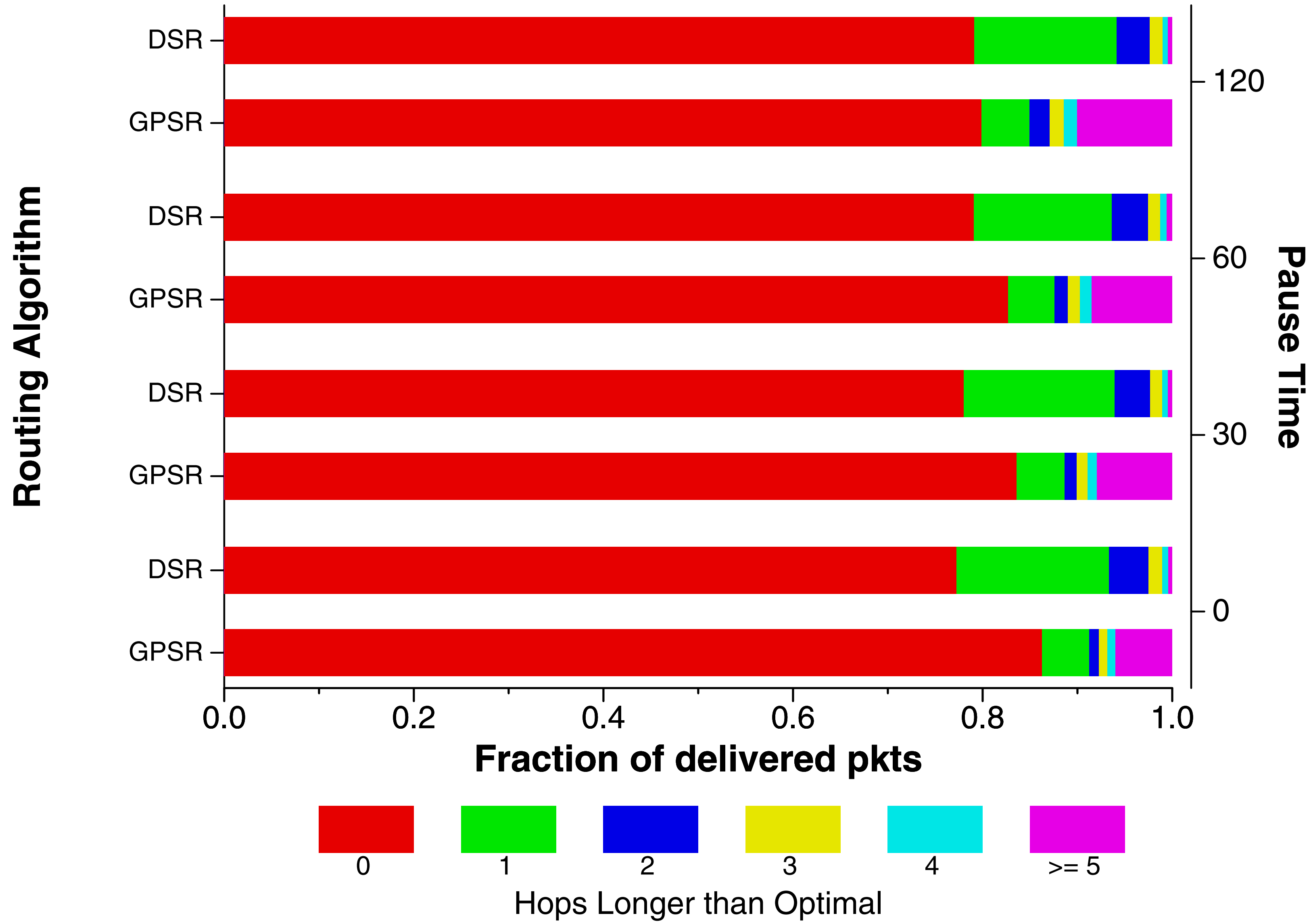
Packet Delivery Success Rate (50; Sparse)





Path Length (50; Dense)
Routing Algorithm
DSR
GPSR
DSR
GPSR
DSR
GPSR
DSR
GPSR
120
60
30
0
Pause Time
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of delivered pkts
0
1
2
3
4
>= 5
Hops Longer than Optimal

Path Length (50 nodes, Sparse)



Outline

Motivation

GPSR Overview

GPSR's Performance on Sparse Networks: Simulation Results

Planar Graphs and Radio Obstacles: Challenge and Approaches

Geographic Traffic Provisioning and Engineering

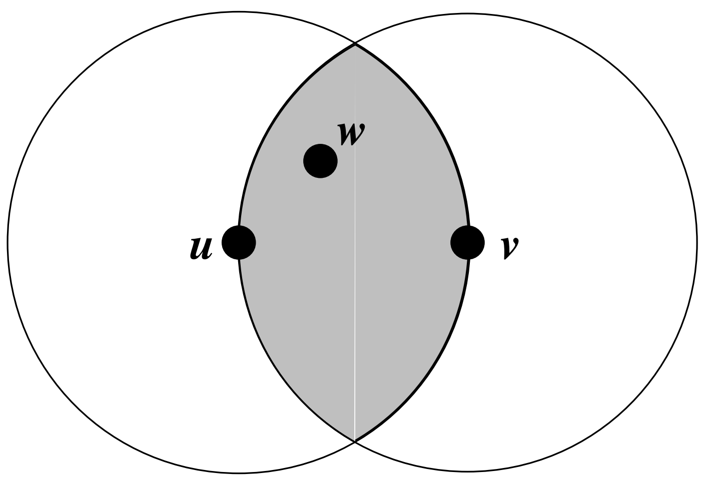
Conclusions

Network Graph Planarization

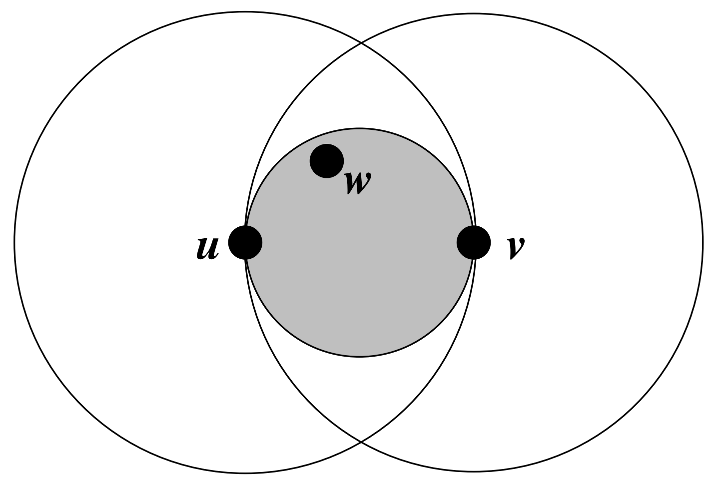
Relative Neighborhood Graph (RNG) [Toussaint, '80] and Gabriel Graph (GG) [Gabriel, '69] are long-known planar graphs

Assume an edge exists between any pair of nodes separated by less than a threshold distance (*i.e.,* the nominal radio range)

RNG and GG can be constructed using only neighbors' positions, and both contain the Euclidean MST!



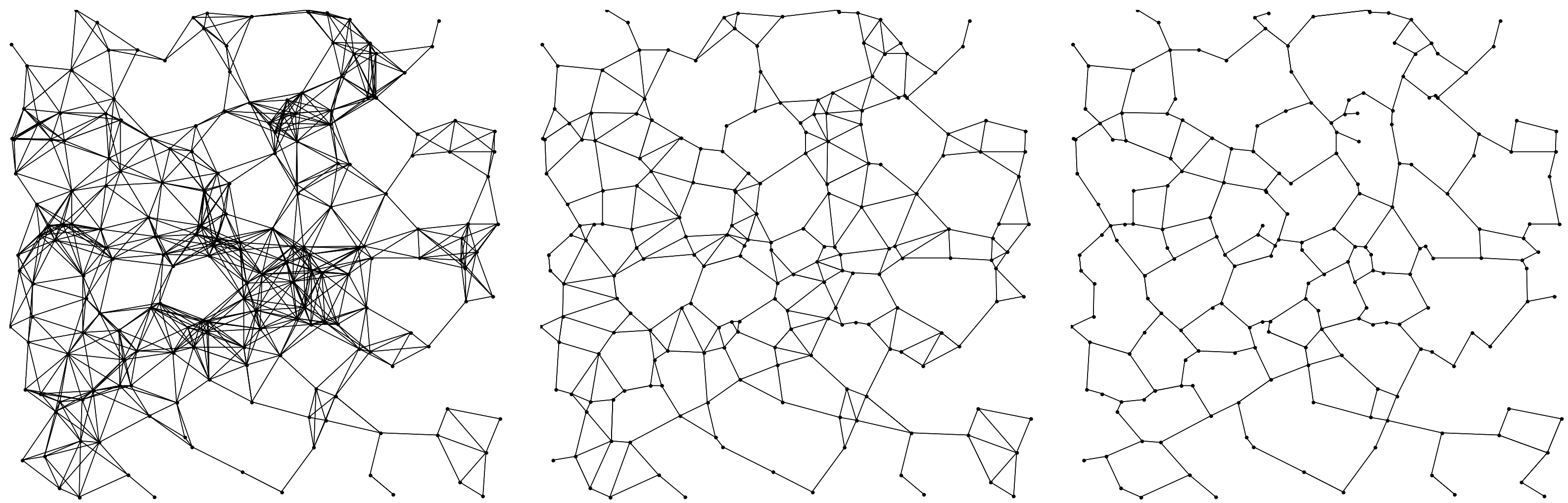
RNG



GG

Planarized Graphs: Example

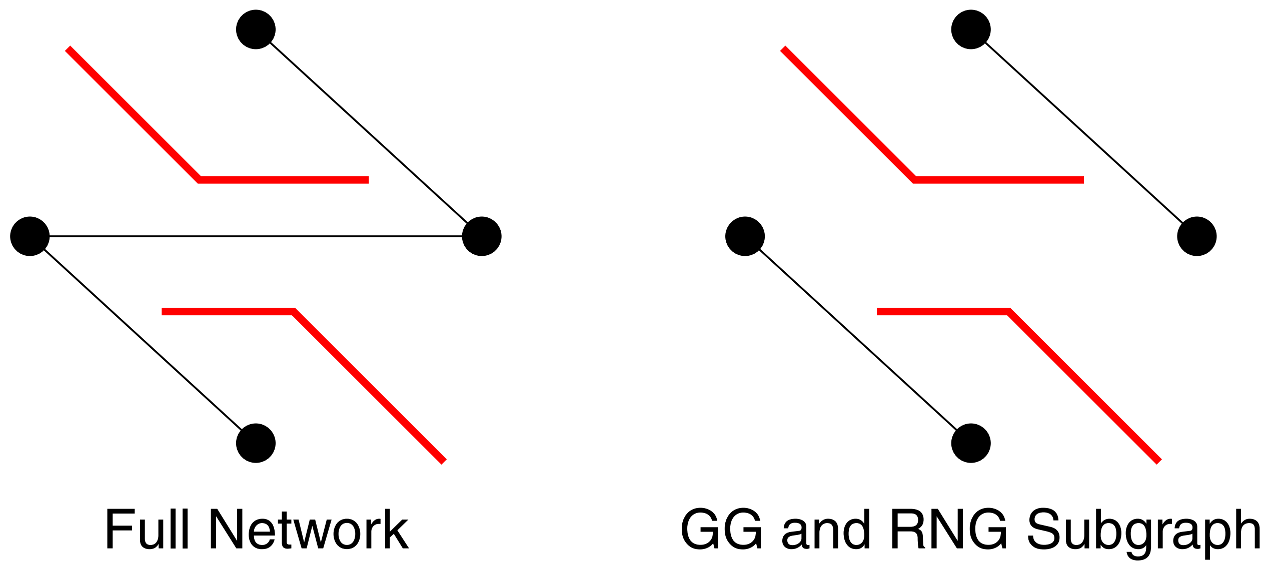
200 nodes, placed uniformly at random on a 2000-by-2000-meter region; radio range 250 meters



Full Network GG Subgraph RNG Subgraph

Challenge: Radio-Opaque Obstacles and Planarization

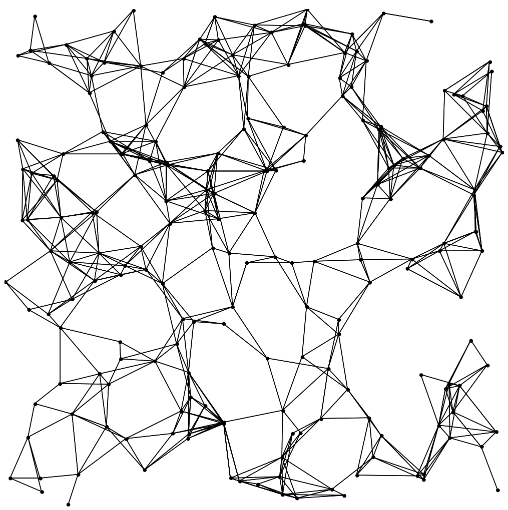
Obstacles violate assumption that neighbors determined purely by distance:



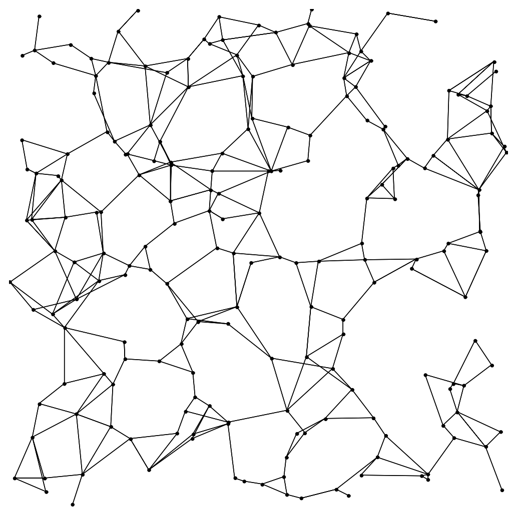
In presence of obstacles, planarization can disconnect destinations!

Coping with Obstacles

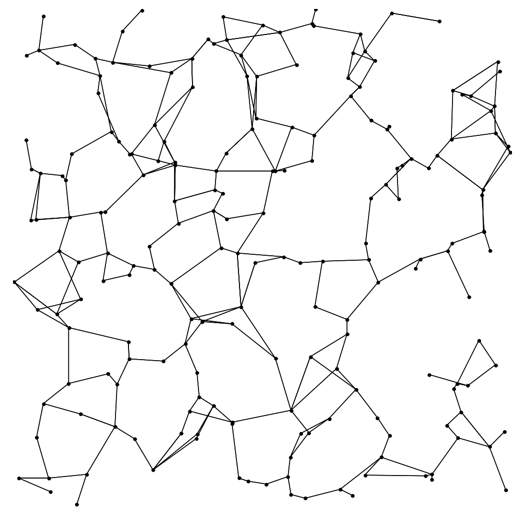
Eliminate edges only in presence of mutual witnesses; edge endpoints must agree



Full Graph



Mutual GG



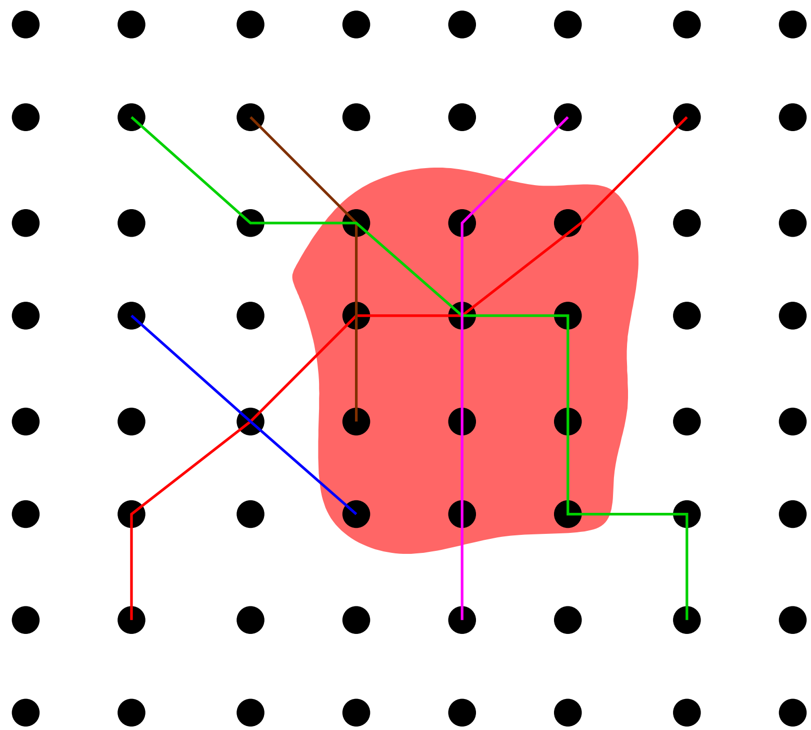
Mutual RNG

Prevents disconnection, but doesn't planarize completely

Forward through a randomly chosen partner node (location)

Compensate for variable path loss with variable transmit power

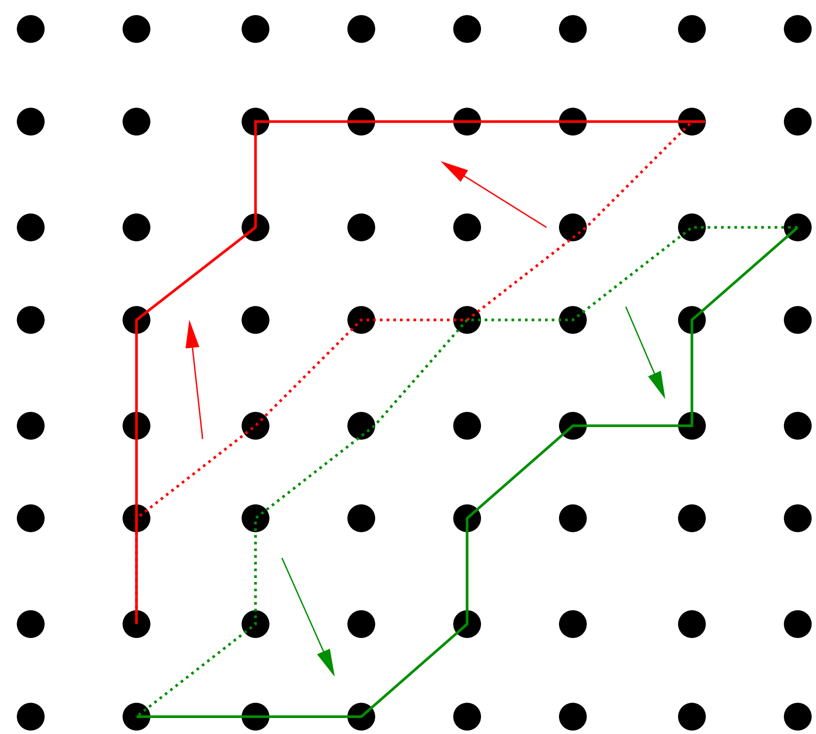
Traffic Concentration Demands *Provisioning*



If we assume uniform traffic distribution, flows tend to cross the center of the network

All link capacities symmetric!

Geographic Network Provisioning



In a dense wireless network, *position is correlated with capacity*

Symmetric link capacity and dense connectivity

Route congested flows' packets through a randomly chosen point

Conclusions

On sparse networks, GPSR delivers packets robustly, most of which take paths of near-shortest length

Non-uniform radio ranges complicate planarization; variable-power radios and random-partner proxying may help

Geographically routed wireless networks support a new, geographic family of traffic engineering strategies, that leverage spatial reuse to alleviate congestion

Use of geographic information offers *diverse* scaling benefits in pervasive network systems